LINKING MICROWAVE REMOTE-SENSING MEASUREMENTS TO FUNDAMENTAL NOISE STANDARDS

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I. INTRODUCTION

- NIST microwave radiometry effort

  We've been doing noise & antenna metrology separately for 30^+ years; recently began doing remote-sensing radiometry, combining the two.
- Interested in microwave remote sensing of earth from satellites and airplanes, as well as earth-based measurements.
- Various applications: climate monitoring, weather modeling and forecasting, agriculture (moisture content), ...

- Calibration
  - linear radiometers ⇒ need (≥) two standards for calibration.
  - satellites: cold sky, if possible
  - otherwise: hot & cold targets, or injection.
  - need independent cal of targets, comparison to other radiometers, traceability.
- NIST Optical Tech. Div. has such a program for UV, Visible, & IR.

- Want to develop analogous capabilities at microwave & mm-wave frequencies, providing a link between microwave remote-sensing measurements & NIST measurements & standards.
- So, develop (& transfer) a standard for microwave brightness temperature.
- Still in early stages, but some progress made.

OUTLINE

- Theoretical Framework
  - brightness temperature
  - standard radiometer
  - expected uncertainty
  - chamber
- Preliminary measurements
  - antenna
  - brightness temperature
- Summary

II. THEORETICAL FRAMEWORK

Brightness, Brightness Temperature

- Spectral brightness (B_f): power per area per solid angle per frequency interval.
- Ideal black body:

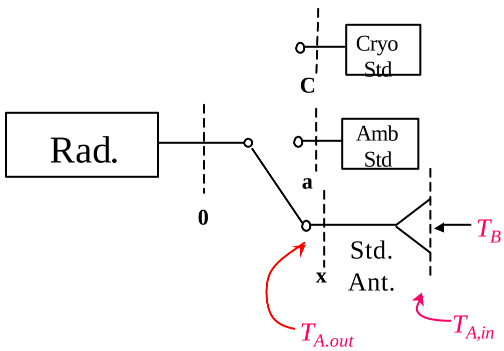
$$B_f = \frac{2}{l^2}\left(\frac{hf}{e^{hf/kT}-1}\right) \approx \frac{2}{l^2} kT \quad (for\ hf << kT)$$

- *Define* brightness temperature:

$$T_B(q, f) \equiv \frac{l^2 B_f(q, f)}{2k}$$

Standard Radiometer

- Radiometer measures $T_{A,out}$; want to determine T_B.
  (n.b.: assume far field conditions.)

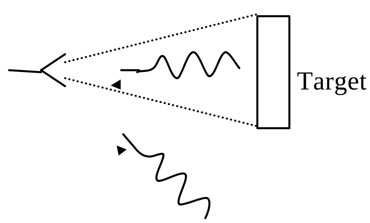


$$T_{A,out} = \alpha T_{A,in} + (1-\alpha) T_a$$

$$T_{A,in} = \frac{\int_{4\pi} T_B(\theta,\phi) F_n(\theta,\phi) d\Omega}{\Omega_p}$$

$$\Omega_p = \int_{4\pi} F_n(\theta,\phi) d\Omega$$

- Break up $T_{A,in}$:



$$\overline{T_T} = \frac{\int_{\text{target}} T_B(\theta,\phi) F_n(\theta,\phi) d\Omega}{\int_{\text{target}} F_n(\theta,\phi) d\Omega}$$

$$\overline{T_{BG}} = \frac{\int_{\text{other}} T_B(\theta,\phi) F_n(\theta,\phi) d\Omega}{\int_{\text{other}} F_n(\theta,\phi) d\Omega} .$$

$$\eta_{AT} \equiv \frac{\int_{\text{target}} F_n(\theta,\phi) d\Omega}{\Omega_p}$$

$$T_{A,in} = \eta_{AT} \overline{T_T} + (1-\eta_{AT}) \overline{T_{BG}}$$

- So,

$$T_{A,out} = a\, h_{AT} \overline{T}_T + a\,(1 - h_{AT})\overline{T}_{BG} + (1 - a)T_a$$

- Control the background, $\overline{T}_{BG} = T_a$
- Then

$$\overline{T}_T = T_a + \frac{1}{a\, h_{AT}}\left(T_{A,out} - T_a\right)$$

- So we need $a \approx 1/L$ and h_{AT}

$$h_{AT} \equiv \frac{\int_{\text{target}} F_n(q, f)\, dW}{W_p}$$

Uncertainties

- Approximate achievable uncertainties:

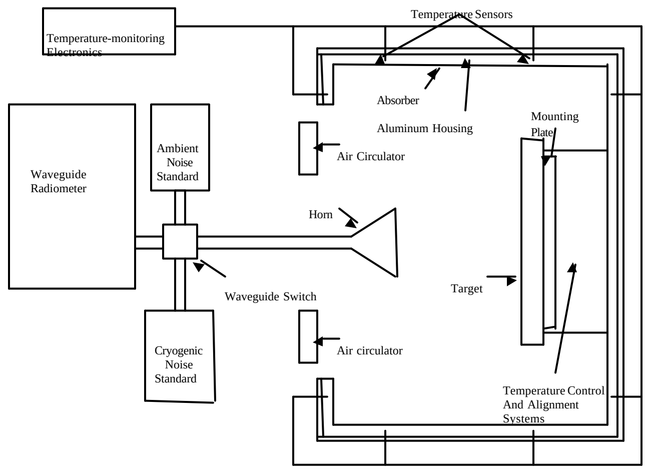
$$u^2(\overline{T}_T) = \left(1 - \frac{1}{a\, h_{AT}}\right)^2 u^2(T_a) + \left(\frac{1}{a\, h_{AT}}\right)^2 u^2(T_{A,out}) + (\overline{T}_T - T_a)^2 \left(\frac{u^2(h_{AT})}{h_{AT}^2} + \frac{u^2(a)}{a^2}\right)$$

$u(T_a) \approx 0.2$ K
$u(T_{A,out}) \approx 0.3 – 0.5$ K (for $T_{A,out}$ = 200 to 300 K,
18 – 26.5 GHz)
$u(h_{AT}) \approx 0.003$
$u(a) \approx 0.005$

- So should be able to get
$u(\overline{T}_T) \approx 0.3$ K to 0.7 K
for $T_{A,out}$ = 200 to 300 K, 18 – 26.5 GHz.

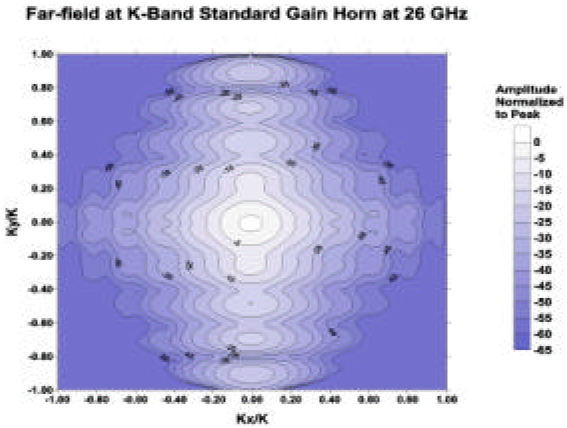
Chamber

- Will need a chamber to control background.

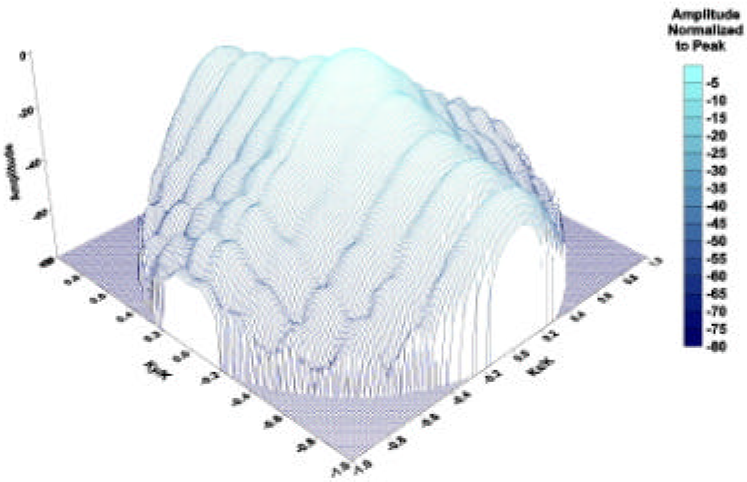


III. MEASUREMENTS (PRELIMINARY)

- Measured antenna pattern for a standard-gain horn (SGH) on the near-field range.

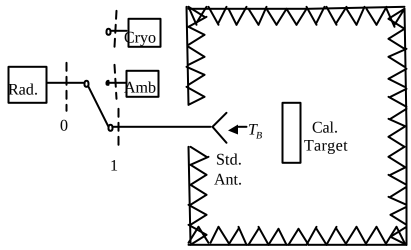


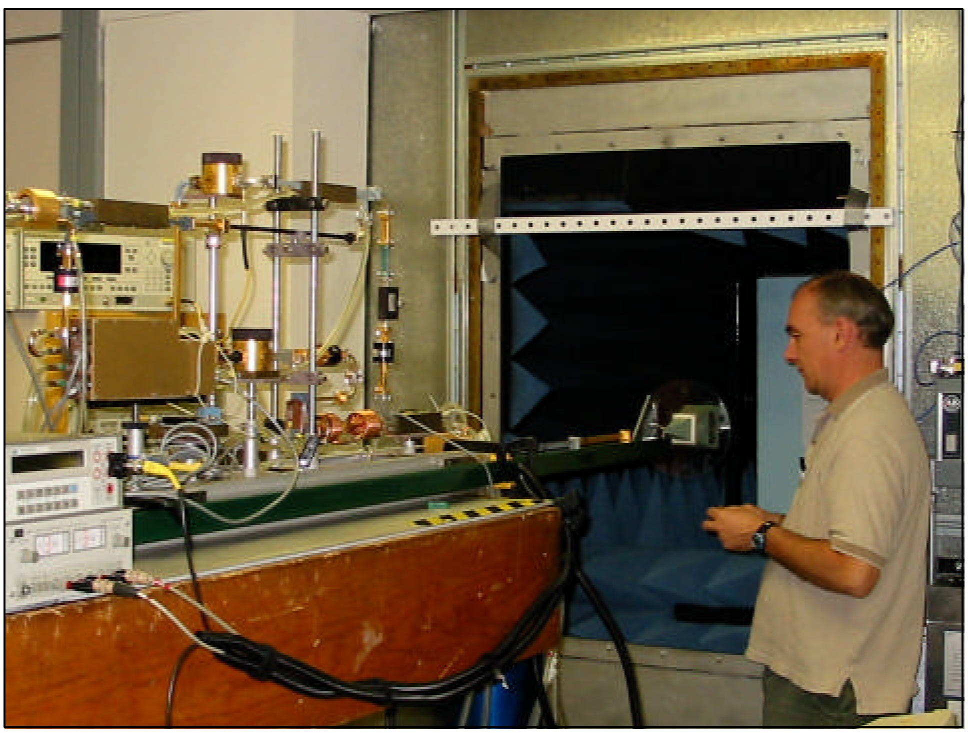
Far-field at K-Band Standard Gain Horn at 26 GHz

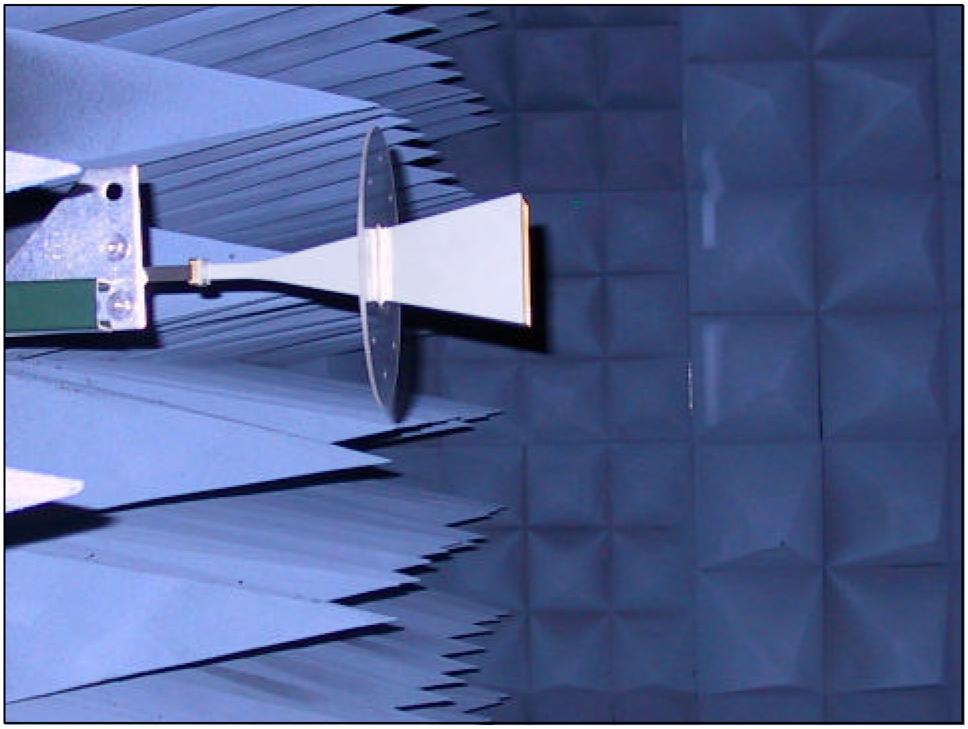


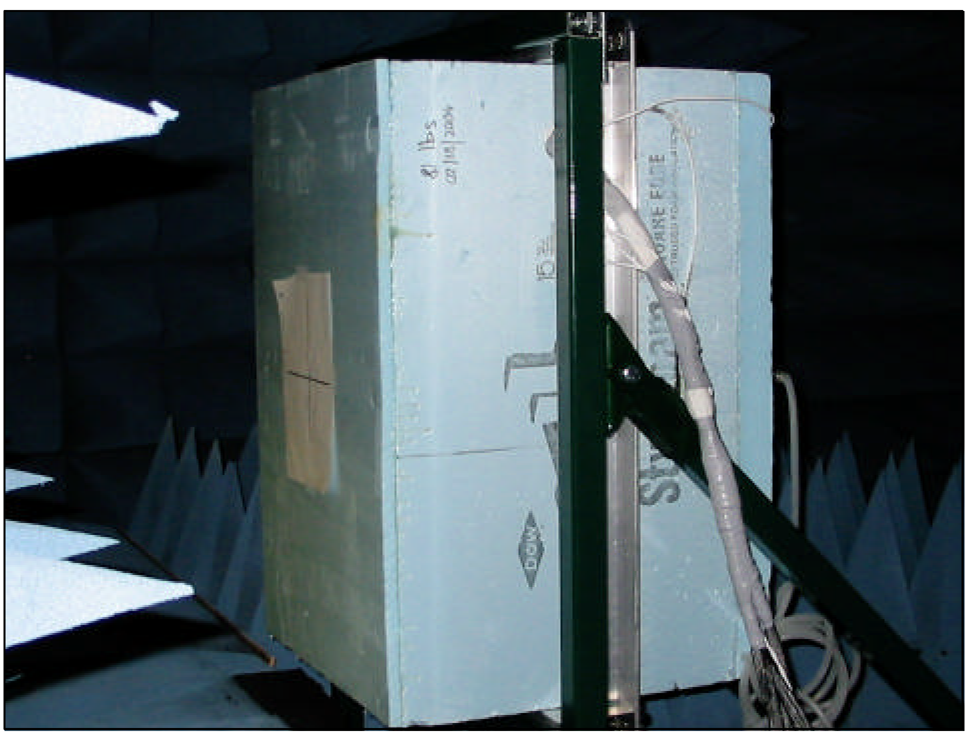
- Integrate pattern to get h_{AT}; value depends on frequency & distance. At 26 GHz, $h_{AT} = 0.980$ at 50 cm, $h_{AT} = 0.301$ at 5 m.
- Compute a from conductivity. $a = 0.9954 \pm 0.0023$ at 26 GHz.
- Connected SGH to the DUT plane of the WR-42 (18 – 26.5 GHz) waveguide radiometer.

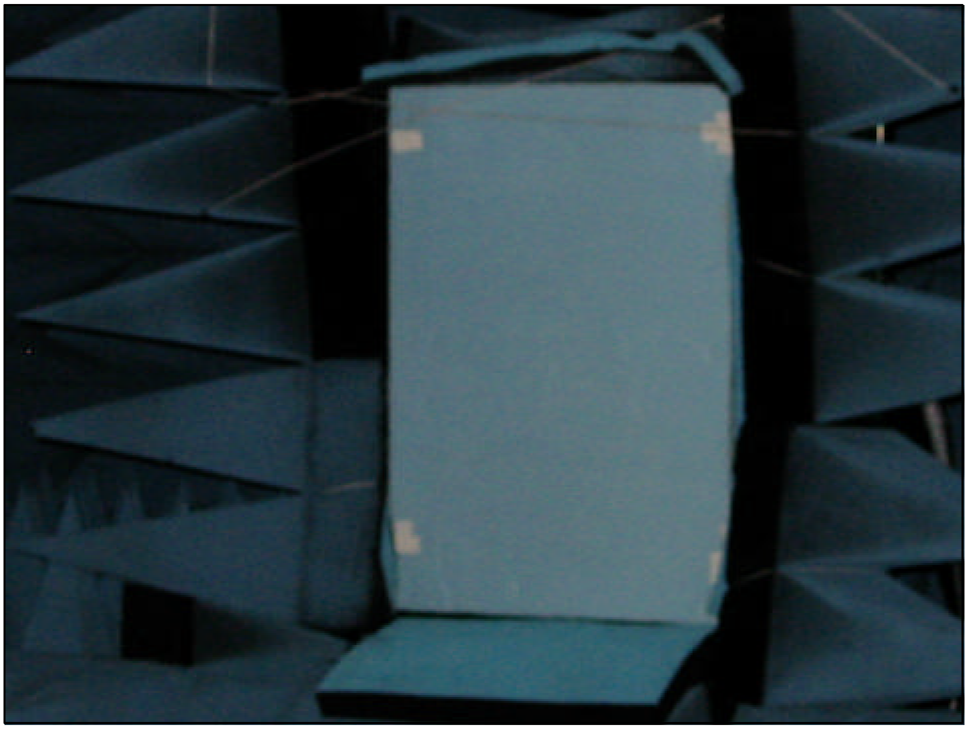
- Borrowed a hot calibration target from NOAA GRS (Al Gasiewski & Marian Klein, NOAA ETL).
- Measured it in the NIST anechoic chamber at 18, 22, & 26 GHz for several distances.



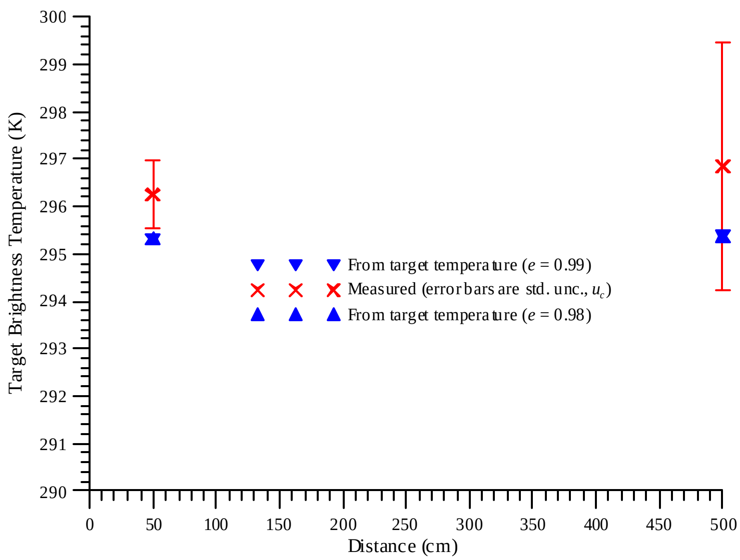




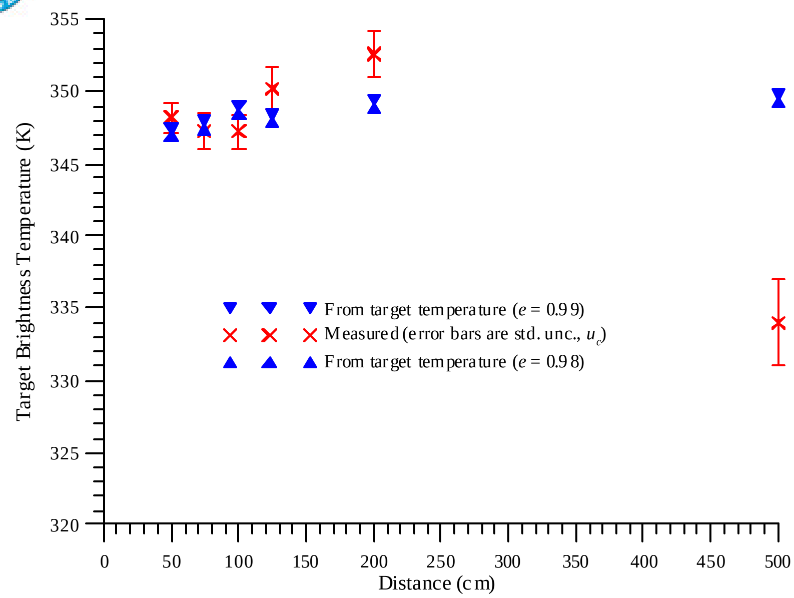

8 lbs
DOW



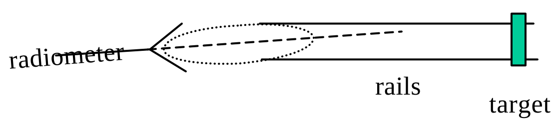
- Results



Target Brightness Temperature (K)
300
299
298
297
296
295
294
293
292
291
290
From target temperature (e = 0.99)
Measured (error bars are std. unc., u_c)
From target temperature (e = 0.98)
0
50
100
150
200
250
300
350
400
450
500
Distance (cm)



- 5 m results discrepancy probably just due to (mis)alignment.



- Uncertainty large due to large $u(h_{AT})$ = 0.0153. Would be $u(h_{AT}) \approx 0.003$ if we knew target location better.

- Issues:
  - – Type A uncertainties (target drift)
  - – Target location & angles
  - – Alignment of radiometer & target
  - – Near/Far field
  - – Emissivity: $T_T = eT_{target} + (1 - e)T_{refl}$, e = ?

V. SUMMARY

- Developing a microwave (18 – 65 GHz) brightness-temperature standard based on existing noise standards and radiometers, plus antenna characterization.
- Have developed framework and performed preliminary measurements.
- Expect uncertainties of about 0.5 – 0.7 K for T_B = 200 to 300 K, f = 18 – 26 GHz. (Larger uncerts for higher/lower temperatures and/or higher frequencies.)

- Next:
  - – further preliminary measurements (different target)
  - – design & build special-purpose chamber
  - – measurements in special-purpose chamber
  - – develop standard target

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